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OPINION

A just energy transition requires research at the intersection of policy and technology

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The current energy system, in the US and around the world, is rife with inequities [1]. The coming energy transition to a low carbon world has the potential to right some of these; but, without intention, it is more likely to perpetuate the current inequities [2]. Enabling a just energy transition will require multiple categories of action, including fair policies and regulations; data and metrics; and knowledge generation. I focus on this last point, and particularly research at intersection of energy technology and social equity.

Research focussed on technological solutions is a crucial enabler for the energy transition, but is not enough: if not intentional, the resulting solutions will support the status quo, not equity. For example, carbon capture is a technological solution to address climate change, but may exacerbate local pollution in marginalized communities [3]. Nor is it enough to design policies and regulations for today's energy system: tomorrow's system will be different and complex. For example, Kirchhoff's laws and other technological realities of the electricity system mean that policies and regulations can lead to significant unintended consequences [4].

Ravikumar et al. [5] provide a set of recommendations for funders on how the energy research process can be harnessed to ensure "an equitable, technology-informed, clean energy transition." These recommendations include centering equity; engaging community input; developing mechanisms to resolve challenges related to community engagement; expanding proposal review criteria; and instituting structural reforms aimed at supporting interdisciplinary research.

I provide three examples of areas of scientific and technological research for energy transition that should be fully integrated with social equity concerns. These provide a starting point for thinking about how to embed equity throughout technologically-focussed research as well as why it is important for equity researchers to be aware of developments in emerging technologies.

Carbon capture, whether at point sources such as coal generation plants, or Direct Air Capture, is a controversial technology on many fronts; with promise to address climate change, but many technical, economic, and justice questions. Marginalized communities are concerned about local pollution and resulting health impacts if fossil and biomass plants are allowed to continue to operate; as well as broader social justice issues around continued use of fossil fuels [6]. Nevertheless, the recent Inflation Reduction Act in the US has significant support for Carbon Capture and Storage, and the United States Department of Energy (DOE) is funding research in this area. In a call for proposals from spring 2021, the DOE acknowledged equity concerns, asking for equity evaluations of later stage projects in the proposals.

It would be impactful, however, to address equity questions starting at the level of more basic science, such as the design of catalysts, membranes, and other important aspects of carbon capture systems. Ideally, research would think about how the justice implications interact

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with the specific technological designs this research will support. For example, questions around local pollution may be partially addressed through technologies that capture all local pollutants and not just CO2. Being aware of this need may change the direction of the research. It will connect natural scientists and engineers with equity researchers, to influence the path that inventions will take. Having equity researchers involved early on will inform harm reduction measures in policy, regulation, and implementation; and it is important for equity researchers to understand the evolution of the technology and the complexities of how it works within the electricity system.

Materials science is a key driver for the energy transition, including research to support batteries, solar, wind turbine blades, catalysts and more. As materials scientists develop new and improved materials, their inevitable reliance on conventional sources of elements and compounds may have justice implications in terms of the full lifecycle, including mining, health and safety for workers and for consumers, disposal, and wealth generation [7]. Early integration with justice research may impact the direction of research for the materials scientists; for example, rather than focusing on an element (such as lithium or cobalt) that causes environmental destruction and human suffering in the homelands of vulnerable populations [8], they could turn their attention to less harmful substitutes. One direction for research that requires collaboration between materials scientists and equity researchers is the derivation of an equity checklist for materials research, in the vein of existing environmental impact or hazardous materials checklists (eg. https://www.epa.gov/hw/inspection-checklist-tool-facilities-generating-and-recycling-hazardous-secondary-materials). If social justice researchers are aware of emerging materials, they can devise ways to measure the impacts of these materials and to regulate them in ways that enable justice.

Fair and unbiased **algorithms** [9] for the energy transition requires both technological expertise and equity expertise. Utilities can employ data science algorithms to optimize locations and maintenance schedules for infrastructure, and to target households for energy efficiency upgrades and subsidies. If these algorithms ignore equity, they can end up perpetuating current inequities. For example [10], finds that homes identified as energy efficient, and therefore not good candidates for subsidies in a data-driven analysis [11], were overwhelmingly in the lowest income decile, possibly due to lack of air conditioning or economizing behaviors [12]. Data scientists working to develop analytically efficient methods to support decisions in the energy transition much work closely with equity researchers to assure these kinds of biases don't appear. At the same time, equity researchers can work with data scientists to increase the impact of metrics and assessments through replicability.

Algorithms may also play an important role in demand side management. Algorithms can ensure efficient operation and potentially transfer some of the immense value that can be gained by such programs to the consumers [13]. But, these kinds of programs can be seen as intrusive [14]; and this may be particularly problematic for traditionally marginalized communities, who often have lower trust due to previous experience [15]. Thus, it is crucial that research on these algorithms and associated implementation programs integrates equity perspectives from traditionally marginalized communities.

This list is not comprehensive, but rather provides some ideas and examples of where energy justice can be pushed forward by research that integrates STEM-focused technology research with social science and humanities-focused energy justice research.

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